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(54) WASTE TREATMENT PROCESS AND APPARATUS

(71) We, TELECOMMUNICATIONS INDUSTRIES, INC., of 1375 Akron Street, Copiague, New York 11726, United States of America, a corporation organised and existing under the laws of the State of New York, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention lies in the field of waste treatment. Waste such as municipal sewage or industrial effluent contains many inorganic, organic, and harmful microbiological materials, most of which are only partially degraded by conventional treatments. Chemical oxidation has been suggested for use to convert such materials to removable and harmless oxides but oxidation processes heretofore utilized have been inefficient and have only been capable of oxidizing a small portion of the contaminants normally found in domestic or industrial waste.

Thus, oxidants such as potassium permanganate ($KMnO_4$) and chlorine (Cl_2) have been used in many localities to disinfect or to improve the taste and ordor qualities of municipal drinking water. These chemicals are not practical for waste treatment, however, because they lack sufficient oxidizing power to degrade many waste constituents and because they leave residual permanganate and chlorine, as the case may be, which must be removed before the treated water can be reused or returned to the natural environment.

Ozone has also been used in the past to treat contaminated articles or water (U.S. Patents 3,445,001, 3,549,528, 2,812,861). Unlike the materials just mentioned, ozone is an extremely powerful oxidant, yet it does not leave a harmful residue. As is well-known, the ozine molecule (O_3) is unstable and decomposes to oxygen (O_2) over a relatively short period of time. Thus, ozone does have the potential oxidizing power for waste treatment and its residue (oxygen) is beneficial rather than harmful. However, ozone has not heretofore been used for bulk waste treatment because means have not been available wherein ozone could be made to effectively react with the solid constituents of waste and, in any event, the cost of the necessary quantity of ozone required for bulk waste treatment has been prohibitive.

Another serious problem faced in the waste treatment art has been the inability to handle the solid constituents normally found in waste water. Waste effluent such as raw or secondary sewage normally contains a substantial quantity of solids which are difficult to handle physically and are difficult to oxidize.

Conventional mechanical means for breaking down solids in waste solutions often are unsatisfactory or fail entirely due to the large mass of the material being treated and/or the nature of these solids. A gummy or sticky residue can be the result of such mechanical treatment. For this reason, the art has, on occasion, suggested the use of sonic energy in the treatment of waste materials for purposes such as removing solids from filtering screens and/or precipitating solid particles (U.S. Patent 3,489,679), breaking certain kinds of emulsions (U.S. Patent 3,200,567), mixing, solubilizing, or causing the reaction of gases (U.S. patents 3,549,528, 2,717,874), or killing microorganisms (U.S. Patent 3,366,654). Mechanical oscillations have also been suggested for stirring and/or promoting aeration or settling of waste materials (U.S. Patents 3,264,213 and 2,770,593).

Additional background which may be of interest may be found in the following:

(U.S. Patents)

3,123,043	1,195,067	2,958,655	2,771,416
3,382,980	2,138,349	3,068,172	2,864,502
3,421,999	2,417,722	3,481,868	2,874,316
3,546,114	3,320,161	2,660,559	3,158,530
			3,448,045

(Other References)

Treatment with Ozone—D. C. O'Donovan—Journal American Water Works Association, Vol. 57, No. 9, 1965.

Disinfection of Drinking Water with Ozone—V. A. Hann, Journal American Water Works Association, Vol. 48, No. 10, 1956.

The Advanced Waste Treatment Research Program—1962—1964, U.S. Department of Health, Education and Welfare, AWTR-14, April, 1965.

Development of a New Type of Rapid Sand Filter—R. E. Hebert, Journal of the Sanitary Engineering Division, proceedings of The American Society of Civil Engineers, Vol. 92, No. SA1, 1966.

A New Method of Treatment for Surface Water Supplies—E. W. J. Diaper—presented at the Fall meeting of the New York Section, AWWA, 1969.

Action of Ozone on Tastes and Odors and Coliform Organisms—Marcus P. Powel et al.—Journal of American Water Works Association, December, 1952.

The Ozonation of Turret and Other Scottish Waters—R. M. Campbell and M. B. Pescod—Journal of Institute of Water Engineers, 19:2:101—125, 1965.

Use of Ozone in the Reclamation of Water from Sewage Effluent—P. L. Boucher et al.—paper presented at a meeting of The Institution of Public Health Engineers, London, December, 1967.

Chemical Engineering, March 1958—pp. 63, 64.

Put Ozone to Work Treating Plant Waste Water—Plant Engineering—November, 1966.

Ozone Counters Waste Cyanide's Lethal Punch—Chemical Engineering, March 24, 1958.

The Ozonation of Cyanide Wastes—Richard G. Tyler, Purdue University, 1951.

Ozone in Air Pollution Abatement—W. E. Cromwell, I/EC Industrial Wastes, Workbook Feature, June, 1959.

Ozonation at Whiting: 26 years later—James F. Bartuska—Public Works, August, 1967.

In view of the need and the problems in the art as aforesaid, the present invention provides a process and apparatus for waste treatment which at least minimizes the aforesaid disadvantages of the prior art.

According to the present invention there is provided a process for purifying waste water, which comprises: (A) imparting acoustic energy to the waste water to cause cavitation thereof; and (B) then ozonating the waste water.

Also in accordance with the invention there is provided a waste water treatment apparatus which comprises: (I) an acoustic chamber; (II) means for imparting acoustic energy to said chamber sufficient to cavitate waste water contained therein; and (III) means for ozonating said waste water.

In accordance with a further aspect of the present invention there is provided a process for the acoustic treatment and ozonation of waste water, which comprises: (A) placing the waste water into a vessel; (B) diffusing an ozone-containing gas stream into the vessel from a plane covering an effective cross-sectional area of the vessel, whereby the vessel is divided into an upper section and a lower section and (C) imparting acoustic energy to said lower section at an energy level to cavitate the waste water which is subsequently ozonated in the upper section.

There is also provided, in accordance with the present invention, an acoustic treatment and ozonation apparatus comprising a vessel; means for imparting acoustic energy into a lower section of the vessel; means for diffusing gas into an upper section of the vessel, so as to provide a gaseous barrier separating the upper and lower sections, the barrier permitting the passage of liquid and preventing the passage of acoustic energy; an ozone generator; means for passing a flow of ozone and oxygen from the ozone generator to the diffusion means; gas outlet means communicating with the upper section; and means for recycling gas from the gas outlet means to the ozone generator.

By use of the process and/or apparatus of the invention, waste waters, containing highly contaminated materials, can be treated to form a product such as potable water.

Various embodiments of the present process and apparatus are illustrated in the accompanying drawings:

Figure 1 is a schematic flow diagram showing how waste water (1) is cavitated and emulsified in acoustic chamber or zone (2) by acoustic waves or energy (3) from transducers (4). The emulsion thus obtained is ozonated in ozone contact chamber (8) to provide potable water (23) or (26). Figure 1 also shows preferred features wherein gas emitting from the ozone contact chamber or zone (8) is recycled (12) via ozone stabilizer (13) which is shown in Figures 8 and 9 and is discussed in detail hereinafter. Figure 1 shows another preferred feature wherein the ozonated liquid (23) is passed into a venting chamber (24), preferably a free-fall spill chamber, so that gaseous oxide products of the ozonation are vented to the atmosphere (25).

Figure 2 is a schematic diagram illustrating a preferred embodiment of the invention wherein both the acoustical cavitation-emulsification step and the ozonation step are carried out within the same chamber (30). The chamber (30) is a combined acoustic treatment and ozone contact chamber. Chamber (30) is effectively divided into an acoustic treatment zone (31) and an ozone

contact zone (32) by a gaseous barrier (37) created by the upward flow of ozone bubbles (35) emitting from diffusers (36).

Figure 3 is a schematic diagram illustrating a preferred arrangement for placement of ozone diffusers (53) and transducers (56) within a combined acoustic treatment and ozone contact chamber (51). Dimensions (A), (B), (C), (D) and (E) are preferably proportioned to create a resonant circuit which provides highly efficient utilization of acoustic energy.

Figure 4 is a drawing of a preferred tube-type diffuser (57) having fins (58, 59) thereon and which is useful in the apparatus of Figures 2 and 3.

Figure 5 is a top view of the diffuser of Figure 4 showing a preferred arrangement of perforations (58) therein which are progressively larger downstream from the ozone inlet (59).

Figures 6 and 7 are end and top views respectively of the diffuser of Figures 4 and 5 showing preferred placement of fins (61, 62) in relation to the placement of perforations (63, 64 and 65) to provide even distribution of ozone emitting into the ozone contact zone and to create the gaseous barrier between the ozone contact zone and the acoustic contact zone as described under Figure 2. Dimensions (I), (J), (K), (L), (M), (N), (O) and (P) are also preferably proportioned to enhance the resonant circuit described under Figure 3.

Figure 8 shows a side view, taken at the centerline, of a preferred ozone stabilizer useful in the gas recycle circuit shown in Figures 1 and 2. Positioned within the ozone stabilizer (68) are felt filters (69, 70), a cellulose filter (72) and a swirl chamber (73) having a plurality of perforations (74) thereon arranged in a helical pattern.

Figure 9 is a top view of the ozone stabilizer of Figure 8 taken at line 9—9.

Any type of industrial or domestic waste water can be treated and purified by utilization of the process and apparatus of the present invention. Examples of such waste waters are polluted river water, raw sewage, secondary sewage, and industrial effluent. These waste waters normally comprise a high level of solids in aqueous solution. Preferably, the waste waters to be treated contain from 1% to 50% by weight, most preferably 5% to 30% solids, the particle size of said solids ranging from 2 microns to 4 inches, preferably from 4 microns to 2 inches.

The waste water which is to be treated in the present invention can be contaminated with many forms of microorganisms and bacteria including pathogenic bacteria and virus. The water can also be contaminated or polluted with such materials as sulphur, iron, manganese, lignite, tannin, phosphates, nitrates, acids, chlorine, cyanide, and common organic wastes such as synthetic detergent residues and fecal matter.

The microorganisms and contaminants just described are destroyed and effectively removed from waste waters by the process of the invention. The result obtained from the process is potable water which can be used directly or returned to the natural water table.

It has been discovered that ozone exerts an unexpected effect on waste waters which have been cavitated by acoustic energy as described herein. Although ozone is a known oxidizing agent and disinfectant, it has not heretofore been deemed capable of achieving the results obtained with the present invention such as (1) actually clarifying waste waters by degrading the solids contained therein to innocuous gaseous oxides, and (2) effectively killing a broad spectrum of microorganisms and toxins found in waste materials, especially solids-containing materials. The unique and beneficial effect of ozone on waste waters is obtained herein is directly related to the treatment of such waters which have previously been cavitated with acoustic energy.

With respect to the acoustic treatment step, any of the well-known transducers capable of generating the desired acoustic energy for cavitation can be used. However, lead zirconate block transducers are highly preferred because of their inherent qualities of high acoustical energy transfer, i.e., 90% efficiency, and high Curie Point. Thus, with lead zirconate transducers, high power can be used with no transducer degradation.

Square wave acoustic energy rich in harmonic frequencies and having little side lobe suppressions is preferred. Such wave properties enhance the desired cavitation.

The power supplied to the transducers, and the other parameters of the acoustic treatment, can vary depending on the size and shape of the acoustic treatment zone and the waste load to be treated. Preferably, power of from 100 kw to 10,000 kw, most preferably 500 kw to 1000 kw, and most highly preferably about 500 kw, is supplied at a mean frequency of 20 kc/sec to 70 kc/sec, most preferably about 28 kc/sec, to lead zirconate transducers having a 20° to 60°, most preferably about a 30°, beam pattern to provide complete acoustic coverage of the acoustic chamber at a level of 140 to 145 KBV.

As noted above, waste waters to be treated normally comprise solids in water. The solids have air or other gas bubbles trapped within. Acoustic energy in water, with sufficient power and frequency, penetrates through the solids to the very core of the mass. Cavitation of the solids occurs in the acoustic treatment step of the process as the resonant frequency of the mass is reached. As this frequency is approached, the mass begins to vibrate,

exciting the bubbles trapped within. Due to the excitation, the pressure within the bubbles builds up to approximately double its initial pressure and this pressure ultimately breaks the solids into smaller pieces. The broad band of acoustic frequencies then reaches the resonant frequencies of the smaller pieces and they begin to break up into even smaller pieces in the same manner. As this cavitation process continues, the smaller particles become emulsified with the solution. After cavitation has occurred, which preferably produces substantially complete emulsification, the ozone is added in order to conduct the ozone treatment step of the process.

The time of the acoustic treatment can vary with the number of transducers used, the level of power supplied thereto and the load being treated. Generally, however, the acoustic treatment step can be completed in from 1/2 minute to 30 minutes, preferably from 1 minute to 15 minutes, dependent on static or flow conditions of the waste being treated.

High pressures tend to repress cavitation and therefore the acoustic treatment step is preferably conducted under a pressure corresponding to atmospheric pressure.

At the end of the acoustic treatment step, the amount of undissolved solids in the waste water has generally been reduced by 20% to 100%, preferably 40% to 90%, of its original value and the particle size of the solids remaining generally ranges from 1 to 20 microns, preferably 1 to 5 microns. At this point, the waste material is in the form of a liquid, readily pumpable emulsion. The term "emulsion" is used herein in its ordinary dictionary sense to mean "a dispersion of fine particles or globules in liquid."

In the second basic step of the process, the emulsion obtained by the acoustic energy in the first step is ozonated by contacting it with ozone. Although any convenient method of contact is suitable, it is preferred to bubble the ozone through the emulsion. This can be done conveniently by diffusing the ozone into the lower extremity of a chamber containing the emulsion and then allowing the ozone to bubble up through the emulsion.

As is well known, ozone (O_3) is an activated form of oxygen (O_2). Ozone is a strong oxidizing agent. Ozone is also relatively unstable and decomposes to oxygen over a period of time.

Ozone for use in the ozone treatment step can be generated by any conventional means, the most convenient method being to pass dry oxygen or dry air through a corona discharge grid. Such ozone generators are commercially available. Ozone generators are not 100% efficient and thus there is always some oxygen or air emitting from an ozone generator. When pure oxygen is used as the feed to the generator, the output usually comprises 3%—8% by volume of ozone, the balance being oxygen. When air is used as the feed to the ozone generator, the output usually comprises 1.75%—5% by volue of ozone, the balance being oxygen and nitrogen.

In the ozone treatment step of the present invention, ozone can be diffused into the emulsion as a gas stream preferably comprising from 0.5% to 10% by volume, most preferably 1% to 4%, of ozone, the balance being oxygen and other gases.

As the ozone contacts the emulsion, it reacts with and oxidizes the contaminants therein and, at the same time, is itself reduced to oxygen. The amount of ozone used depends on the amount of contaminants present in the emulsion. In order to achieve the best possible contact and results, it is preferable to bubble an excess of ozone through the emulsion.

It is preferred to carry out the ozonation at a pressure of about atmospheric or slightly higher in a closed chamber. Sufficient pressure should, however, be maintained on the ozone feed diffused into the emulsion to overcome the pressure head of the liquid emulsion. Accordingly, the pressure in the ozone input line, as well as in the rest of the system, can preferably be maintained within the range of from 1 psig to 30 psig, most preferably 3 psig to 10 psig.

The time of the ozonation step, i.e., the time period during which ozone is diffused into the emulsion, can vary widely depending on the type and quantity of waste material being treated and on the quantity of ozone input. Preferably, the time of ozonation is from 1/2 minute to 30 minutes, most preferably from 3 minutes to 10 minutes, dependent on static or flow conditions of the emulsion being treated.

The excess or residual gas bubbling to the top of the emulsion which comprises ozone along with the oxygen formed by the ozonation reaction and the oxygen bubbled into the emulsion as part of the ozone feed stream, can if desired be released to the atmosphere. However, it is preferred not to so vent the residual ozone and oxygen, but instead to conduct the ozonation in a closed chamber and to collect the gas bubbling from the emulsion and recycle it. Recycling the ozone/oxygen has the advantages of (1) not releasing ozone to the atmosphere thus avoiding any toxic or combustionable dangers associated therewith, especially in an improperly ventilated environment, (2) preserving the amount of oxygen input needed for ozone production and ozonation with attendant cost savings, and (3) providing for enrichment of the ozone feed stream.

It is generally desirable to compress the recycling of the ozone/oxygen stream collected from the ozonation step in order to provide a continuing flow of gas in the system and to

overcome the pressure head of the emulsion when diffusing the ozone feed stream into the emulsion. As is known in the art, compression of ozone tends to be dangerous because of the risk of explosion. Accordingly, a preferred embodiment of the present invention includes a unique step wherein the ozone recycle stream is stabilized prior to compression thereof. This stabilizing step preferably involves mixing the ozone stream with oxygen, in pure form or as air, in a vortex flow whereby the ozone is rapidly decomposed to oxygen and is thus stabilized.

The gas recycle stream may also contain some moisture, for example, 70—80% relative humidity, carried from the waste emulsion and the stream is thus preferably dried prior to stabilization and prior to recycle to the ozone generator. The air or oxygen input to the ozone generator is also preferably dried prior to its use in the generator. Thus, the gas input to the emulsion preferably contains less than 5% relative humidity.

Subsequent to the ozonation step, the ozonated waste water can be agitated and vented to the atmosphere. The agitation, preferably with concurrent aeration, decomposes any residual ozone and releases the gaseous ozonation products of the original contaminants.

The remaining purified solution has desirable odor and color, and is potable. At the end of the process, microorganisms and toxins have been totally destroyed or reduced to innocuous levels and the B.O.D. level in the material has been reduced by 80%—100%, preferably 100%.

The acoustic treatment step and/or the ozonation step do not require high temperatures nor do they generate significant heat. Accordingly, the entire process can be conducted at ambient temperature.

Further details of the invention and other embodiments thereof are set forth in the following discussion of the accompanying drawings.

With reference to Figure 1, waste water input (1), such as sewage, is placed into acoustic treatment chamber (2). The waste water (1) is then subjected to acoustic energy (3), preferably ultrasonic square waves, from high efficiency transducers (4) powered by an oscillator power supply (5). The acoustic waves (3) create cavitation in the solids of the solution which consequently breaks down the solids into extremely fine particles and causes emulsification. That is, the fine particles are dispersed in the liquid. Irrespective of the type of input (1), the solids content therein is substantially reduced by cavitation and emulsification in the acoustical treatment step, and any remaining solids not emulsified can be separated from the chamber via line (6).

The resultant emulsion (7) from the acoustic treatment step is then transferred to an ozone contact chamber (8), which can comprise a closed vessel, and is subjected therein to ozonation by bubbling ozone (9) therethrough. Any residual ozone and/or oxygen which does not react with the waste water being ozonated collects at the top (10) of the ozone contact chamber and can be removed from the chamber through a check valve (11), for example, a float-type valve, which prevents liquid from leaving the confines of the contact chamber (8). The ozone/oxygen thus removed (12) is passed through an ozone stabilizer (13) wherein it is first dried and is then stabilized. Downstream from the stabilizer (13), the now stabilized stream is compressed (14). Make-up air or oxygen can be added to the system at the ozone stabilizer (15) and/or at the compressor (16) in an amount necessary to compensate for the ozone utilized in the ozonation reaction.

The compressed stream (17) is then passed through a dryer (18), preferably a heatless dryer, and then through an ozone generator (19) wherein fresh ozone is generated, for example, by a corona discharge grid, so that the desired level of ozone can be maintained in the feed (20) to the ozone contact chamber (8). The feed stream (20) is routed through a check valve (21) and into the ozone contact chamber (8) via diffusers (22) thus completing the ozonation cycle.

In a subsequent step, the ozonated but substantially ozone-free liquid (23) is transferred to a venting chamber (24) wherein it is vented to the atmosphere so that the oxidation products of the ozonation reaction which are usually in the form of gaseous oxides can escape via vent (25) to the atmosphere leaving purified water (26) as a product. The venting chamber (24) can comprise a free-fall spill chamber wherein the free-fall of fluid (27, 28, 29) between sequentially lower compartments (29*a*, *b*, *c*, *d*) provides agitation and aeration. Any residual ozone in liquid (23) is decomposed and vented as oxygen from chamber (24).

It is convenient to conduct the acoustic treatment step and the ozonation step within the same vessel or chamber. When this is done, care must be taken to separate the injection of the ozone stream into the chamber from the point where cavitation and emulsification of the waste material is to occur. Otherwise, the gaseous bubbles of ozone and oxygen will dampen the acoustic energy and tend to prevent the necessary cavitation of the waste solids.

Accordingly, Figure 2 shows an embodiment of the invention where the acoustic treatment step and the ozone contact step are carried out within the same chamber in a manner which provides separate sections for the acoustic treatment step and the ozone contact step and prevents the ozone bubbles from suppressing the necessary cavitation.

In Figure 2, an apparatus in which the acoustic and gaseous treatments are carried out in the same chamber is shown which broadly comprises: a vessel or chamber (30) for holding liquids and gases; means for imparting acoustic energy (39) into a lower section (31) of the vessel (30); and means for diffusing gas (36) into an upper section (32) of the vessel (30) so as to provide a gaseous barrier (37) separating the upper and lower sections, the barrier (37) permitting the passage of liquid and preventing the passage of acoustic energy.

More specifically, a combination chamber (30) is provided with an acoustic treatment section (31) and an ozone contact section (32), said sections being divided by a barrier which permits the flow of liquid therebetween but is impervious to acoustic energy. When using the combination chamber 30, the waste water is injected at inlet (33) into the lower section of the chamber near the floor (34). Ozone bubbles (35) are admitted into the chamber by diffusers (36) having diffusion holes thereon aimed in a generally upward direction and arranged in a plane covering an effective cross-sectional area of the chamber, for example, covering more than 90% of the cross sectional area. As the ozone input from line (48) is diffused into the chamber, a gaseous barrier (37) is created at the plane of the diffusers (36) which divides the chamber into an acoustic treatment section (31) and an ozone contact section (32). Acoustic waves (38) from transducers (39) cannot pass the gaseous barrier (37) and are thus reflected within the acoustic treatment section (31) wherein the cavitation and emulsification occurs. As the liquid within the acoustic treatment section (31) becomes emulsified, it naturally passes up (40) into the ozone contact section (32) as the gaseous barrier permits liquids to pass therebetween.

The removal and recycle of residual ozone and oxygen via check valve (41) and line (42), through stabilizer (43), compressor (44), and dryer (44a) and ozone generator (45), with provisions for air or oxygen intake (46, 47) and back into diffusers (36) via line (48) can be the same as described above with reference to Figure 1.

The purified water is removed from the upper section of the chamber (30) via treated water outlet valve (49) while excess solids not cavitated and emulsified can be drained by valve (50).

Figure 3 shows a schematic sectional view of a preferred arrangement for a combination acoustic treatment and ozone contact chamber (51) having a plurality of tube diffusers (52) therein, which diffusers are preferably finned (53). The floor (55) of the vessel (51) is lined with transducers (56).

In a preferred mode allowing for high efficiency operation, dimensions comprising the length of the diffusers (A), the distance between the terminal diffuser (52) and the side of the vessel (B), the distance between diffusers (C), the distance between the diffusers and the floor of the vessel (D), and the length of the vessel (E), are proportioned so as to create a resonant circuit; that is, the finned tubes and the walls of the vessel are tuned to provide a resonant circuit. Although these dimensions can vary depending on the desired size of the vessel and the mean frequency of the acoustic energy, illustrative dimensions for a resonant circuit when a preferred mean frequency of 28 kc/sec is used are:

A—185 inches
B— 39 inches
C— 39 inches
D— 39 inches
E—351 inches,

and multiples thereof.

Figure 4 is a pictorial view of a preferred tube-type diffuser (57) having fins (58, 59) thereon such as can be used in the apparatus of Figure 3.

Figure 5 shows a top view of the tube-type diffuser of Figure 4. Preferably, the diffusion holes (58) are progressively enlarged downstream from the ozone inlet end in order to insure an even distribution of ozone within the chamber and to create the gaseous barrier described hereinbefore. As an illustration, the holes can be 0.0135 inches in diameter along the first 1/3 section of the tube (F), 0.028 inches in diameter along the second 1/3 section of the tube (G), and 0.040 inches in diameter along the final 1/3 section of the tube (H).

Figures 6 and 7 respectively show end and top views of a preferred diffuser (60) suitable for use in the apparatus of Figure 3. The fins (61, 62) are so placed with respect to each other and to the diffusion holes (63, 64, 65) so as to provide uniform distribution of ozone into the chamber and to enhance the gaseous barrier and the resonant circuit described above.

Thus, where a preferred mean frequency of 28 kc/sec is utilized, and dimensions (A), (B), (C), (D) and (E) are as set forth hereinbefore, illustrative dimensions in Figure 6 are:

I—1.125 inches
J—0.450 inches
K—0.900 inches
L—0.093 inches
M—0.500 inches
N—0.500 inches
O—100°
P— 30°

When utilizing the preferred embodiments

shown in Figures 3, 4, 5, 6 and 7, it is also preferred to utilize a pulse-power technique for the supply of acoustic energy. For example, square wave acoustic energy can be imparted to the acoustic treatment zone for 30 milliseconds, stopped for 60 milliseconds, imparted for 30 milliseconds and so on. With this technique, the original pulse of acoustic energy emitted from the transducers at the floor of the chamber strikes the gaseous barrier and creates a high standing wave ratio within the acoustic treatment chamber. The standing wave ratio is returned back toward the floor of the chamber, and strikes the floor midway between pulses.

When the power-pulse technique is used with a resonant circuit, a constant wave function results. This provides a highly efficient process. For example, for the same amount of power input to the transducers, the acoustical energy or wavefront imparted to the cavitating solids can be at least doubled.

As discussed hereinbefore, it is preferable when recycling the residual ozone stream to stabilize the ozone therein by mixing it with air or oxygen in a vortex flow.

Figures 8 and 9 respectively show side and top cross-sectional views of a preferred ozone stabilizer for use with the present invention.

Broadly speaking, the apparatus shown in Figures 8 and 9 is an ozone stabilizer which comprises a gas-tight vessel (71*a*), a swirl chamber (73) positioned within the interior of the vessel, a plurality of perforations (74) communicating between the interior of the vessel (71) and the interior (77) of the swirl chamber, means (74*a*) for passing a flow of ozone into the interior of the vessel upstream from the swirl chamber, means (75, 76) for passing a flow of gas into the vessel upstream from the swirl chamber, and means (78) for passing a flow of gas from the vessel downstream from the swirl chamber. In this apparatus, the ozone and the other gas are mixed in the interior (77) of the swirl chamber in a vortex flow.

More specifically, and with further reference to Figures 8 and 9, the ozone stabilizing apparatus can comprise a gas-tight vessel (71*a*) having a gasket (67) in communication with a removable top section (68). A brass or other suitable material swirl chamber (73), positioned within the interior of the vessel, is preferably cylindrical and perforated with a plurality of openings (74), preferably arranged in a helical pattern as illustrated. A flow of ozone-containing gas is passed into the interior of the vessel (71) at inlet (74*a*) upstream from the swirl chamber while a flow of air or oxygen is passed into the interior of the vessel via inlet (75) and/or (76) upstream from the skirl chamber. Filters, which preferably comprise porous felt, can be positioned within the interior of the vessel (71) to remove any moisture present in the ozone and gas streams. As shown (69, 70), the filters can be positioned directly in the flow of the respective gas streams within the interior of the vessel (71). Any moisture not removed by the felt filters is removed by final filter (72) which preferably comprises cellulose fiber in continuous sheet form wrapped around the swirl chamber (73). The dried ozone and air or oxygen streams then pass through the perforations (74) which are preferably positioned at an angle of 45° relative to the axis and the radii of the swirl chamber and thence into the interior (77) of the swirl chamber (73) wherein a vortex flow is created as the gases pass downstream.

The rapid and violent agitation of the ozone with oxygen or air in the vortex flow quickly decomposes ozone to oxygen which is passed as a flow of gas from the vessel via outlet (78) downstream from the swirl chamber. By means of this stabilizer, a moist ozone-containing flow of gas can be rapidly and dependably dried and decomposed to oxygen on a continuous basis. Periodically, the filters can be removed from the stabilizer and dried.

Example

This example illustrates how the process and apparatus of the present invention can be used to treat and purify sewage into potable water.

Two and one-half gallons of effluent taken directly from the input holding tank of a municipal sewage treatment plant was used as the starting waste material in this example. The waste had a pH of 6.5, a pungent, nauseating odor, and had an opaque dark brown appearance. The waste was composed primarily of fecal matter and comprised approximately 10% by weight total undissolved solids, ranging in particle size of from 4—5 microns up to 1/2 inch.

The waste liquid just described was placed in an acoustic treatment chamber comprising a 1/16-inch stainless steel holding tank, having a seven gallon capacity (Model VST-42, 25 kH$_z$, manufactured by Dri-Clave, Inc.). Eight lead zirconate transducers were spaced at equal intervals across the floor of the chamber.

An oscillator power supply (Model No. VSG-42, manufactured by Dri-Clave, Inc.) was connected to the transducers via an output tank circuit. The circuit was adjusted to reflect a saturation condition in the power amplifier tubes and the transducers thus produced a square wave having 400 watts of acoustic power at a mean frequency of 25 kH$_z$, rich in harmonics and low in side lobe suppression.

The waste material in the chamber was subjected to the acoustic energy as described above for thirty minutes. As soon as the acoustic energy was supplied, the solids in

the waste liquid began to cavitate and break apart. As cavitation continued and the particle size of the solids became smaller and smaller, emulsification occurred. At the end of the thirty minute period, the liquid was substantially completely emulsified and contained less than 5% undissolved solids; all of the solids remaining had a particle size of less than 5 microns. The emulsion was in a liquid state and readily pourable.

Two liters of the emulsion thus formed were pumped from the acoustic treatment chamber into an ozone contact chamber.

The ozone contact chamber was cylindrical, 36 inches high with a 3 inch inside diameter. This chamber was fabricated from a transparent inert plastics ("Lucite" (R.T.M.)) and was capped at the top and bottom. The top capping was fitted with a line for residual ozone removal which had a float-type check valve therein to prevent liquid from leaving the ozone contact chamber. Four porous air stone diffusers were fitted at the bottom of the chamber and connected through a bottom fitting to an ozone inlet line.

Ozone was generated by passing dry oxygen through a corona discharge ozone generator of 10,000 volts at 250 watts and having an output capacity of 1.5 pounds of ozone per 24 hour day.

The ozone was fed through the ozone inlet line via a check valve to the porous air stone diffusers. The ozone concentration in the feed to the diffusers was approximately 3% by volume, the balance of gas in the feed comprising oxygen. The pressure in the feed line and in the ozone contact chamber was about 3 psig.

The gas which collected at the top of the ozone contact chamber comprised residual ozone and oxygen. This residual gas was removed from the ozone contact chamber via the float-type check valve and recycled through an ozone stabilizer wherein it was dried and stabilized by decomposing it to oxygen by mixing with oxygen in a vortex flow. The stabilizer comprised a gas-tight vessel containing felt and cellulose filters, and a brass swirl chamber perforated in a helical pattern with holes drilled 45° to the axis and radii, as described above with respect to Figures 8 and 9.

The stabilized, i.e., ozone-free, recycle stream emitting from the stabilizer was passed, along with dry make-up oxygen, through an air compressor. The stream was then passed through a heatless dryer and thence into the ozone generator.

A flow rate of ozone through the ozone contact chamber of 1.5 pounds per 24-hour day was continued for a period of 10 minutes; about 4.7 grams of ozone was used during this time.

As the bubbles of ozone passed up through the emulsion, foaming occurred due to the oxidation of contaminants containted therein. During the 10-minute ozone contact period, the emulsion dramatically changed from opaque dark brown to a translucent amber solution.

At the end of the 10-minute ozone contact period, the liquid, which contained about 1/2 ppm dissolved ozone, was pumped into a venting chamber.

The venting chamber was constructed of a clear, inert plastics ("Lucite") box, 12 inches square and divided into 4 compartments of unequal height. The box was so constructed that the inlet flowed first into the highest compartment and then into each successively lower compartment.

The free fall of the liquid between compartments provided agitation and aeration whereby the residual dissolved ozone was decomposed to oxygen and this oxygen, along with the gaseous oxidation products comprising gaseous oxides of the original contaminants, was vented to the atmosphere.

The purified liquid remaining was odorless and potable.

The data shown in Table I were generated prior to and after the process described above in this example.

TABLE I

Item	Waste Effluent Prior to Treatment	Purified Liquid After Treatment
Odor	Pungent, nauseating	Odorless, neutral
Color	Opaque Dark Brown	Clear light amber
pH	6.5	6.5
Plate Count (total bacteria)	13,400 ppm/ml	133 ppm/ml
Nitrates	250 ppm (est.)	less than 10 ppm
Solids	10% (4—5 microns to 1/2 inch)	1—2% (1—5 microns)
Temperature	25°C.	25°C.

Although the process embodiments of the invention have been described as a batch or step-wise operation, it will be readily apparent to those skilled in the art that the process can be carried out in a continuous manner. Likewise, although the invention has been described utilizing tank-type vessels, the use of tube-type or pipeline reactor vessels is also contemplated.

WHAT WE CLAIM IS:—

1. A process for purifying waste water, which comprises:
(A) imparting acoustic energy to the waste water to cause cavitation thereof; and
(B) then ozonating the waste water.

2. A process as claimed in claim 1 wherein the waste water contains 1% to 50% by weight solids.

3. A process as claimed in claim 2 wherein the particle size of the solids is within the range of from 2 microns to 4 inches.

4. A process as claimed in claim 3 wherein the particle size of the solids is within the range of from 4 microns to 2 inches.

5. A process as claimed in claim 2 wherein the amount of undissolved solids in the waste water is reduced by 20% to 100% in step (A).

6. A process as claimed in claim 5 wherein the particle size of the solids remaining after step (A) is within the range of from 1 to 20 microns.

7. A process as claimed in claim 5 or 6 wherein the amount of undissolved solids in the waste water is reduced by 40% to 90% in step (A) and the particle size of the solids remaining after step (A) is within the range of from 1 to 5 microns.

8. A process as claimed in claim 1 wherein the pressure during step (A) corresponds to atmospheric pressure.

9. A process as claimed in claim 1 wherein the acoustic energy of step (A) comprises square waves.

10. A process as claimed in claim 9 wherein the square wave acoustic energy is rich in harmonic frequencies and has little side lobe suppression.

11. A process as claimed in claim 9 or 10 wherein the square wave acoustic energy is generated by a plurality of lead zirconate block transducers.

12. A process as claimed in claim 11 wherein the power supplied to the transducers is within the range of from 500 kw to 1000 kw at a mean frequency of 20 kc to 70 kc/sec.

13. A process as claimed in claim 12 wherein power is supplied to the transducers at a mean frequency of about 28 kc/sec and the transducers have a beam pattern of 20° to 60°.

14. A process as claimed in claim 12 or 13 wherein the transducers have a beam pattern of about 30° and the square wave acoustic energy has an acoustic pressure of 140 to 145 KBV.

15. A process as claimed in claim 1 whereby step (A) is conducted in an acoustic treatment zone and step (B) is conducted in an ozone contact zone, and in which the acoustic treatment zone is turned to provide a resonant circuit.

16. A process as claimed in claim 15 wherein step (B) comprises diffusing ozone into a chamber containing the waste water and bubbling the ozone through the cavitated waste water.

17. A process as claimed in claim 16 wherein an excess of ozone is diffused into the waste water as a gas stream comprising 0.5% to 10% by weight of ozone.

18. A process as claimed in claim 17 wherein the gas stream is diffused into the waste water at a pressure of 1 psig to 30 psig.

19. A process as claimed in claim 17 or 18 wherein the gas stream is diffused into the waste water from a plurality of finned tube diffusers.

20. A process as claimed in any one of claims 15 to 19 wherein the ozone is generated by passing oxygen through a corona discharge grid.

21. A process as claimed in claim 17 in which in step (B), the residual gas bubbling through the waste water is collected and recycled to the waste water.

22. A process as claimed in claim 21 wherein the recycling comprises (i) collecting the residual gas bubbling through the waste water which gas comprises ozone and oxygen; (ii) stabilizing the gas collected in (i); (iii) compressing the gas stabilized in (ii); (iv) drying the gas compressed in (iii); and (v) generating fresh ozone by passing the gas of (iv) through a corona discharge grid.

23. A process as claimed in claim 22 wherein the gas is dried prior to the stabilization of step (ii).

24. A process as claimed in claim 22 or 23 wherein the stabilization step (ii) comprises mixing the gas with air or oxygen in a vortex flow whereby ozone contained in the gas is decomposed to oxygen.

25. A process as claimed in any one of claims 1 to 24 wherein a subsequent step (C) comprises agitating and venting the ozonated water of step (B).

26. A process as claimed in claim 25 wherein the agitation and venting is conducted by passing the ozonated water of step (B) through a free-fall spill chamber.

27. A process as claimed in claim 25 or 26 wherein the liquid remaining after step (C) is potable water.

28. A process for purifying waste water as claimed in any one of claims 1 to 27 substantially as hereinbefore described.

29. A waste water treatment apparatus which comprises (I) an acoustic chamber; (II) means for imparting acoustic energy to said chamber sufficient to cavitate waste water contained therein; and (III) means for ozonating said waste water.

30. An apparatus as claimed in claim 29 wherein (II) comprises a plurality of lead zirconate transducers powered by 500 kw to 1000 kw at a mean frequency of 20 kc to 70 kc/sec.

31. An apparatus as claimed in claim 29 or 30 wherein (III) includes: (i) an ozone contact chamber having gas inlet means and gas outlet means; (ii) an ozone generator; (iii) means for diffusing ozone into the ozone contact chamber from the ozone generator; (iv) means for recycling gas from the gas outlet of the ozone contact chamber to the ozone generator.

32. An apparatus as claimed in claim 31 wherein the ozone generator comprises a corona discharge grid.

33. An apparatus as claimed in claim 31 or 32 wherein the ozone contact chamber is closed to the atmosphere.

34. An apparatus as claimed in claim 31, 32 or 33 wherein the diffusion means comprise a plurality of finned tubes.

35. An apparatus as claimed in any of claims 31 to 34 wherein the recycle means comprise: (a) means for stabilizing the ozone and oxygen in the ozone and oxygen-containing gas stream emitting from the gas outlet; (b) means for compressing the stabilized gas; (c) means for drying the compressed and stabilized gas; and (d) means for feeding the dried gas to the ozone generator.

36. An apparatus as claimed in claim 35 which includes means for drying the ozone and oxygen emitting from the gas outlet upstream from the stabilizing means.

37. An apparatus as claimed in claim 35 or 36 wherein the stabilizing means comprises means for mixing the ozone and oxygen with oxygen in a vortex flow.

38. An apparatus as claimed in claim 37 wherein the stabilizing means comprises: a gas-tight vessel; a swirl chamber positioned within the interior of the vessel; a plurality of perforations communicating between the interior of the vessel and the interior of the swirl chamber; means for passing a flow of ozone into the interior of the vessel upstream from the swirl chamber; means for passing a flow of gas into the vessel upstream from the swirl chamber; and means for passing a flow of gas from the vessel downstream from the swirl chamber, whereby the ozone and gas are mixed in the swirl chamber in a vortex flow.

39. An apparatus as claimed in claim 38 wherein the swirl chamber is cylindrical and the perforations are arranged in a helical pattern.

40. An apparatus as claimed in claim 38 or 39 which includes drying means comprising filters positioned within the interior of the vessel upstream from the swirl chamber and downstream from where the ozone and gas are passed into the vessel.

41. A waste water treatment apparatus as claimed in any one of claims 29 to 40, substantially as hereinbefore described with reference to and as illustrated in Figs. 1, 8 and 9 of the accompanying drawings.

42. A process for the acoustic treatment and ozonation of waste water, which comprises: (A) placing the waste water into a vessel; (B) diffusing an ozone-containing gas stream into the vessel from a plane covering an effective cross-sectional area of the vessel, whereby the vessel is divided into an upper section and a lower section and (C) imparting acoustic energy to said lower section at an energy level to cavitate the waste water which is subsequently ozonated in the upper section.

43. A process as claimed in claim 42 or 43 wherein the vessel is closed to the atmosphere; gas is collected from the upper section and is recycled to the said ozone-containing gas stream.

44. A process as claimed in claim 43 wherein the recycle comprises: drying the ozone and oxygen collected from the upper section; stabilizing the ozone by mixing it with oxygen in a vortex flow to decompose the ozone to oxygen; compressing the oxygen; passing the oxygen through a corona discharge grid; and passing the ozone-containing gas stream emitting from the grid into the vessel in accord with step (B).

45. A process as claimed in claim 42, 43 or 44 in which, in step (B) the gas stream is diffused into the vessel from a plurality of finned tube diffusers positioned across said plane.

46. A process as claimed in any one of claims 42 to 45 wherein the acoustic energy imparted in step (C) comprises square wave acoustic energy rich in harmonic frequencies with little side lobe suppression.

47. A process as claimed in claim 46 wherein the acoustic energy is generated by a plurality of lead zirconate block transducers positioned across the floor of said vessel and powered with 500 kw to 1000 kw at a mean frequency of 20 kc to 70 kc/sec.

48. A process as claimed in any one of claims 42 to 47 wherein the lower section of the vessel is tuned to provide a resonant circuit.

49. A process as claimed in claim 48 wherein the acoustic energy is imparted in step (C) in pulses so timed that the reflection of acoustic energy from the gaseous barrier reaches the floor of the vessel midway between pulses.

50. A process as claimed in claim 49 wherein the acoustic energy is present within

the lower section as a constant wave function.

51. A process for the acoustic treatment and ozonation of waste water as claimed in any one of claims 42 to 50, substantially as hereinbefore described.

52. An acoustic treatment and ozonation apparatus for carrying out the process of any one of claims 42 to 51 which comprises: a vessel; means for imparting acoustic energy into a lower section of the vessel; means for diffusing gas into an upper section of the vessel so as to provide a gaseous barrier separating the upper and lower sections, the barrier permitting the passage of liquid and preventing the passage of acoustic energy; an ozone generator; means for passing a flow of ozone and oxygen from the ozone generator to the diffusion means; gas outlet means communicating with the upper section; and means for recycling gas from the gas outlet means to the ozone generator.

53. An apparatus claimed in claim 52 wherein the gaseous barrier is formed by diffusing gas into the vessel from diffusers positioned in a plane covering an effective cross-sectional area of the vessel.

54. An apparatus as claimed in claim 53 wherein the diffusers comprise finned tubes having diffusion holes thereon aimed in a generally upward direction.

55. An apparatus as claimed in claim 52, 53 or 54, wherein the means for imparting acoustic energy comprises a plurality of lead zirconate block transducers positioned across the floor of the vessel and powered with 500 kw to 1000 kw at a mean frequency of 20 kc to 70 kc/sec.

56. An apparatus as claimed in claim 52, 53, 54 or 55 wherein the ozone generator comprises a corona discharge grid.

57. An apparatus as claimed in any one of claims 52 to 56 wherein the recycle means comprises: (i) means for stabilizing the ozone in the ozone and oxygen-containing gas stream emitting from the gas outlet; (ii) means for compressing the stabilized gas; (iii) means for drying the compressed and stabilized gas; and (iv) means for feeding the dried gas to the ozone generator.

58. An apparatus as claimed in claim 57 which includes means for drying the ozone and oxygen emitting from the gas outlet upstream from the stabilizing means.

59. An apparatus as claimed in claim 57 or 58 wherein the stabilizing means comprises means for mixing the ozone and oxygen with oxygen in a vortex flow.

60. An apparatus as claimed in claim 57 wherein the stabilizing means comprises: a gas-tight vessel; a swirl chamber positioned within the interior of the vessel; a plurality of perforations communicating between the interior of the vessel and the interior of the swirl chamber; means for passing a flow of ozone into the interior of the vessel upstream from the swirl chamber; means for passing a flow of gas into the vessel upstream from the swirl chamber; and means for passing a flow of gas from the vessel downstream from the swirl chamber, whereby the ozone and gas are mixed in the swirl chamber in a vortex flow.

61. An apparatus as claimed in claim 60 wherein the swirl chamber is cylindrical and the perforations are arranged in a helical pattern.

62. An apparatus as claimed in claim 61 which includes drying means comprising filters positioned within the interior of the vessel upstream from the swirl chamber and downstream from where the ozone and gas are passed into the vessel.

63. An acoustic treatment and ozonation apparatus as claimed in any one of claims 52 to 61, substantially as hereinbefore described with reference to Figs. 2 to 9 of the accompanying drawings.

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1389291 COMPLETE SPECIFICATION

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Sheet 1

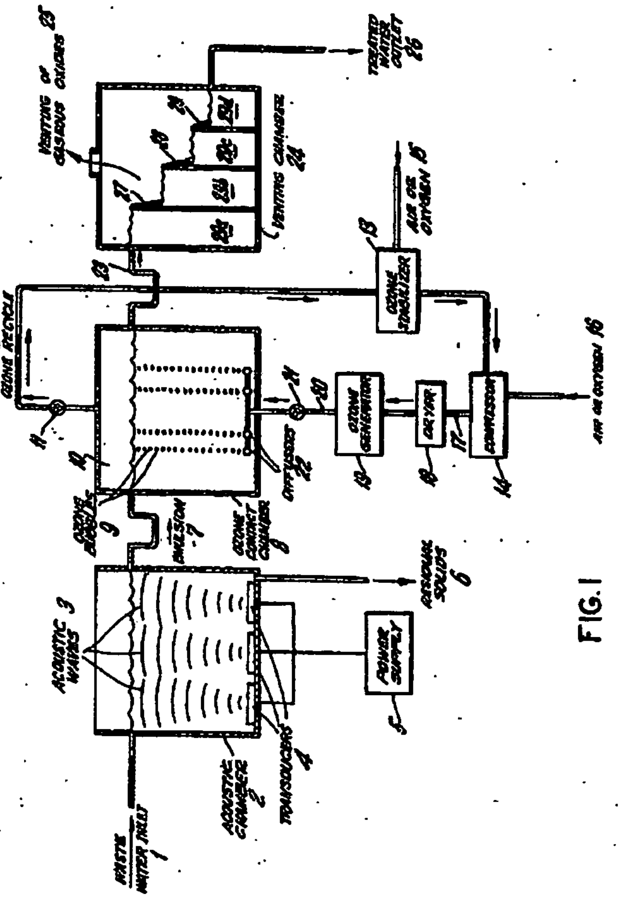

FIG. 1

1389291 COMPLETE SPECIFICATION

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Sheet 2

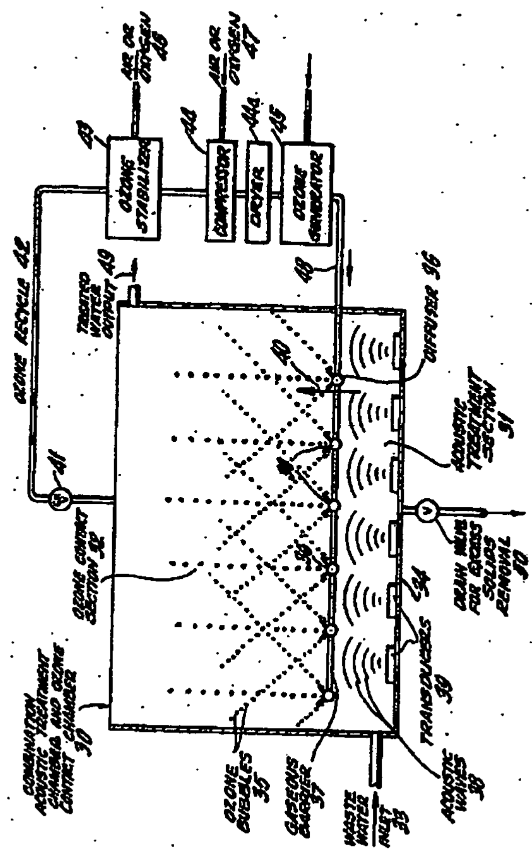

FIG.2

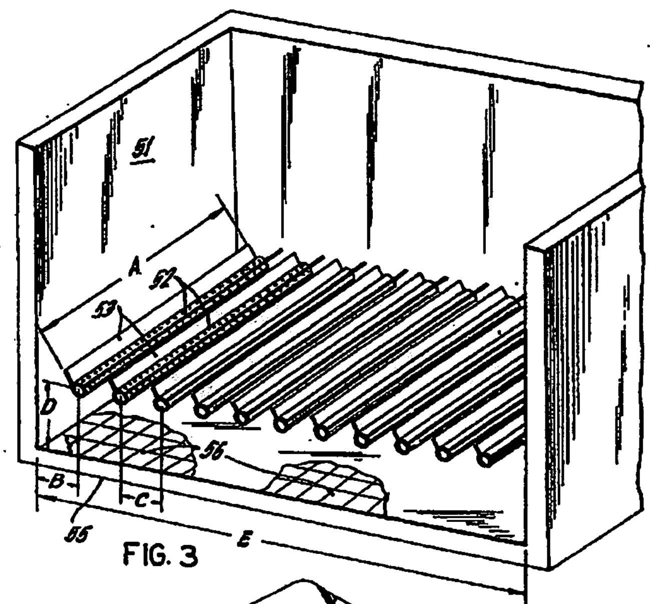

FIG. 3

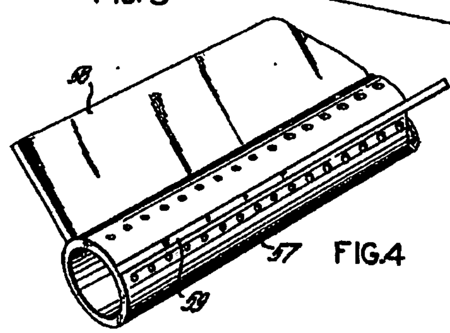

FIG.4

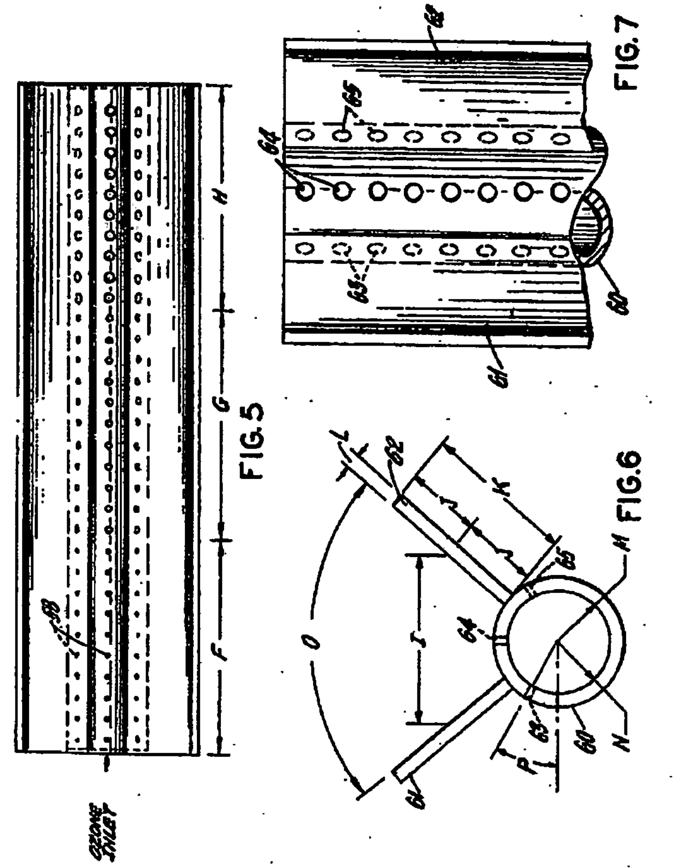

FIG.5

FIG.6

FIG.7

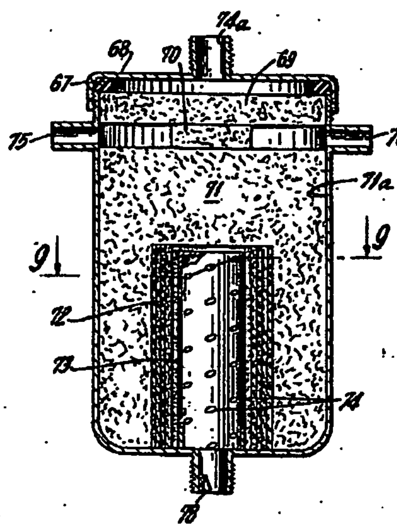

FIG.8

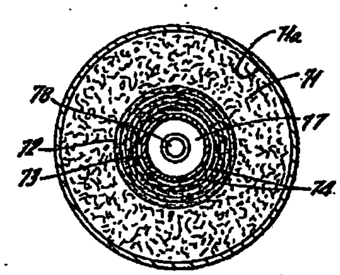

FIG.9